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IN THE UNITED STATES
PATENT AND TRADEMARK OFFICE

Patent No.	:	6,861,979	Confirmation No. 6396
Issued	:	March 1, 2005	
Appl. No.	:	10/798,536	
Applicants	:	Mark I. Zhodzishsky	
	:	Victor A. Veitsel	
	:	Andrey V. Narizhny	
Docket No.	:	1010-0001-USA	
Title	:	METHOD AND APPARATUS FOR DETECTING ANOMALOUS MEASUREMENTS IN A SATELLITE NAVIGATION REEIVER	

Attention: Certificate of Corrections Branch
Commissioner for Patents
PO Box 1450
Alexandria, Virginia 22313-1450.

REQUEST FOR CERTIFICATE OF CORRECTION UNDER 37 CFR 1.322

Patentee hereby requests a Certificate of Correction under 37 CFR 1.322 in order to correct PTO mistakes in the above identified patent.

The text of the requested corrections are set forth in the enclosed Certificate of Correction form PTO/SB/44, with the location of the errors in the printed patent identified by column/claim and line numbers.

The requested corrections were incurred through the fault of the PTO. This request is supported by documentation showing that the requested corrections were included in the application as filed. This documentation includes copies of the relevant pages of the application as filed as well as a cross reference identifying the location of each error in the patent and its corresponding location in the application as filed.

I hereby certify that this correspondence, as well as any items referred to as being transmitted herewith, is being deposited with the United States Postal Service with sufficient postage as first class mail in an envelope addressed to: Commissioner for Patents, P.O. Box 1450, Alexandria, VA 22313-1450 on March 21, 2005.

Typed or printed name of person signing this certificate: Risa Garcia

Signature: Risa Garcia

Expedited processing of this Request is hereby requested.

Respectfully,

Jeffrey M. Weinick

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Dated: March 21, 2005

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PTO/SB/44 (04-04)
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UNITED STATES PATENT AND TRADEMARK OFFICE
CERTIFICATE OF CORRECTION

PATENT NO. : 6,861,979

DATED : March 1, 2005

INVENTOR(S) : Mark I. Zhodzishsky, Victor A. Veitsel, Andrey V. Narizhny

It is certified that error appears in the above-identified patent and that said Letters Patent is hereby corrected as shown below:

Column 13, line 35, " π_z ", should read -- Π_χ --.

Column 14, line 17, " π_z ", should read -- Π_χ --.

Column 14, line 43, "$\Phi c^5(i)$", should read -- $\Phi c^s(i)$--.

Column 17, line 43, " π_z , should read -- Π_χ --.

Column 18, line 11, "$\Phi c^5(i-1)$", should read -- $\Phi c^s(i-1)$--.

Column 18, line 14, "$\Phi c(i)$", should read --$\Delta\Phi c(i)$--.

Column 18, equation (19) should read --$\Delta\Phi c(i)= \Delta\Phi c(i) - \Phi c^s(i-1)$--.

Column 19, line 41, the equation in claim 3 should read

-- $\Phi c_j= (\Phi^B{}_{2j} - \Phi^R{}_{2j}) - (\Phi^B{}_{1j} - \Phi^R{}_{1j})(f2 / f1)$--.

Column 22, line 6, the equation in claim 23 should read

-- $\Phi c_j= (\Phi^B{}_{2j} - \Phi^R{}_{2j}) - (\Phi^B{}_{1j} - \Phi^R{}_{1j})(f2 / f1)$--.

MAILING ADDRESS OF SENDER: PATENT NO. 6,861,979

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No. of additional copies

CROSS-REFERENCE OF ERRORS IN PATENT WITH LOCATION IN APPLICATION AS FILED

REQUEST FOR CORRECTION	LOCATION OF CORRECT TEXT IN APPLICATION AS FILED
Column 13, line 35, " π_z ", should read -- Π_χ --.	Page 18, line 1
Column 14, line 17, " π_z ", should read -- Π_χ --	Page 18, line 32
Column 14, line 43, "$\Phi c^5(i)$", should read -- $\Phi c^s(i)$--.	Page 19, line 17
Column 17, line 43, " π_z , should read -- Π_χ --.	Page 23, line 19
Column 18, line 11, "$\Phi c^5(i-1)$", should read -- $\Phi c^s(i-1)$--	Page 24, line 9
Column 18, line 14, "$\Phi c(i)$", should read --$\Delta\Phi c(i)$--.	Page 24, line 11
Column 18, equation (19) should read --$\Delta\Phi c^c(i) = \Delta\Phi c(i) - \Phi c^s(i-1)$--	Page 24, line 12
Column 19, line 41, the equation in claim 3 should read, -- $\Phi c_j = (\Phi^B{}_{2j} - \Phi^R{}_{2j}) - (\Phi^B{}_{1j} - \Phi^R{}_{1j})(f2 / f1)$--	Page 27, claim 3, line 6
Column 22, line 6, the equation in claim 23 should read, -- $\Phi c_j = (\Phi^B{}_{2j} - \Phi^R{}_{2j}) - (\Phi^B{}_{1j} - \Phi^R{}_{1j})(f2 / f1)$--.	Page 31, claim 23, line 5

probability distribution law one can determine the threshold Π_χ to which the value χ^2 is to be compared to result in a relatively small acceptable probability of false alarm. For example, an appropriate threshold is approximately P_{fa}=0.01...0.05, where χ^2 is calculated by equation (11). If the threshold is exceeded, then it is determined that an anomalous measurement has been detected. Once the anomalous measurement is detected, a determination of the particular channel having the anomalous measurement is made by repeatedly removing channels from the χ^2 calculation in a manner similar that as described above in accordance with the first described embodiment of the residual analyzer 320.

A third embodiment of the residual analyzer is also based on criteria χ^2, but locates the channel with the anomalous measurement in a different way. Once the threshold has been exceeded, it is assumed that an anomalous measurement exists in one channel only and the channels are eliminated one by one. However, upon eliminating a particular channel and recalculating χ^2, if the threshold remains exceeded using the remaining n=N-1 channels, then the particular channel is returned to the set of channels used in the calculation of χ^2 and a second channel is eliminated. Again, χ^2 is recalculated with the remaining n=N-1 channels. A first search continues in this manner until either the one channel having the anomalous measurement is found, or after eliminating all channels and the threshold continuing to be exceeded, it is determined that more than one channel has an anomalous measurement. In the latter case, a second search is initiated now eliminating channel pairs and computing χ^2 using n=N-2 channels. A second search continues in this manner until either the two channels having the anomalous measurements are found, or after eliminating all channel pairs and the threshold continuing to be exceeded, it is determined that more than two channels have anomalous measurements. In the latter case, a third search is initiated now eliminating channels in groups of three and computing χ^2 using n=N-3, and searching again as described above. Searching continues in this manner until either all the channels that contain anomalous measurements are found, or the number of the channels remaining is equal to two.

The three above described embodiments of the residuals analyzer 320 are appropriate where the integrated discriminator 308 generates the average estimate of phase mismatches $\Delta\Psi$ according to equation (3). The operation of the residual analyzer 320 is altered as follows if the integrated discriminator 308 generates the average estimate of phase mismatches $\Delta\Psi$ according to equation (5). First, the search is stopped when the number of remaining channels is five. Second, the degree of freedom for the calculation of the threshold Π_χ in the second and third

residuals analyzer embodiments described above is n-4. Third, each time a new channel or channels is eliminated from the calculation, the integrated discriminator 308 recalculates matrix G using the remaining channels. In yet another alternative, in the case in which the receiver is a dual-frequency receiver and phase difference is calculated using equation (1), if the search stops when the number of channels reaches five, it may be continued by calculating phase difference with equation (2) rather than equation (1). This results in locating more channels with anomalous measurements.

Following the analysis of the residuals, the decision module 322 makes a decision based on the analysis. In one embodiment, the decision may be to merely transfer to the navigation location determining module 206 (Fig. 2) the information so far obtained about the anomalous measurements so that the navigation location determining module 206 may consider this information in solving the navigation task. If the combined phase difference is defined by equation (1), then the anomaly indicator module can also calculate an estimate of cycle slips to allow the navigation location determining module 206 to correct for such cycle slip. The estimate $\mathbf{\Phi c}\,^{s}\mathbf{(i)}$ is based upon rounding the residuals and may be calculated as follows:

$$\mathbf{\Phi c}\,^{s}\mathbf{(i)} = 0.5\ \mathrm{round}(\boldsymbol{\delta}\mathbf{(i)} / 0.5), \qquad (12)$$

where $\mathbf{\Phi c}\,^{s}\mathbf{(i)}$ is the vector of estimates (in semi-cycles) of anomalous errors (cycle slips), $\boldsymbol{\delta}\mathbf{(i)}$ is the vector of residuals for the deleted channels, and round (...) is the operation of rounding to the nearest integer.

In addition, the anomaly module can transfer to the navigation location determining module 206 information about channel indicator alarms 324 that mark the appearance of strong perturbations in the channels. These alarms are received from the channel indicators which operate as described below.

One skilled in the art would recognize that the navigation location determining module 206 may use the information received from the anomaly indicator module 210 in various ways. For example, the navigation location determining module 206 may miss ignore an *i-th* measurement, eliminate corrupted channels or give them less weight, apply corrections to slips, or use the measurements of all the channels in coordinate determination.

We now describe the operation of the channel indicators. The task of the channel indicators is to detect disturbance in the satellite channels that may cause anomalous phase measurements and to mark (i.e., flag) the channels with an alarm.

$$\delta(i) = A \cdot \delta(i - 1) + \Delta\delta(i), \qquad (17)$$

where A is a coefficient that determines time constant and the gain of the filter-integrator, where $A < 1$. The recommended value for A is in the range A=0.995…0.999. In normal mode the integrated residuals represent small noise fluctuations. When an anomalous measurement appears the integrated residual of the corresponding channel increases and the sum of squares residuals between channels also increases.

The residuals analyzer 516 and the decision module 518 may operate in a manner similar to that described above in accordance with the residuals analyzer 320 and decision module 322 of Fig. 3. However, in the embodiment under present discussion, the operations of the residuals analyzer 516 and decision module 518 must be carried out with the integrated residuals.

It is also possible to use the χ^2 criteria (as described above) only to determine the existence of anomalies, and to use channel indicator alarms 520 to determine the location of the channel on which the anomaly has occurred. (It is noted that this alternative is also applicable to the first and third embodiments of the anomaly indicator.) In accordance with this alternative, all channels marked with alarm flags are eliminated from the anomaly indicator module's calculations as described above, and then the above described χ^2 criteria is utilized for the remaining channels. Depending on the result, the following decisions can be made.

If the number of channels remaining is not less than four and χ^2 is less than the threshold Π_χ, then in addition to transferring information about the corrupted channels to the navigation location determining module 206, the decision module 518 can also measure anomalous errors in those channels using equation (12) to apply cycle-slip-corrections to $\mathbf{\Phi c(i)}$. After applying the corrections, the residuals analyzer 516 can again use the χ^2 criteria to assess the corrections applied. Further, it is possible to continue verifying the validity of the channel alarms by, for example, returning certain channels previously eliminated from the anomaly indicator module's calculations, when the flags/alarms of the amplitude and angle indicators were different. It is noted that if it is impossible to satisfy χ^2 criteria then *i-th* measurement should be considered as uncertain.

Fig. 6 shows a functional block diagram of a third embodiment of the anomaly indicator in which initial ambiguities are deleted due to processing the increments of combined phase differences over the interval from initial to current measurements. In addition, this embodiment of the indicator module is based upon the readings of the channel indicators. As represented in block 602 the inputs of the anomaly indicator module are single differences of full phases

measured at the Base and Rover for each satellite. The combined phase difference generator 604 generates the vector **Φ c(i)** of combined phase difference as described above in accordance with equation 13. Operator 606 generates the increment vector as follows:

$$\Delta\Phi c(i) = \Phi c(i) - \Phi c(0), \qquad (18)$$

where **Φ c(0)** is the value of the combined phase difference at the initial moment (i=0), the initial moment being reset periodically by the initial time moments reset unit 608, with a period equal to approximately 50 … 100 seconds and also resetting upon the appearance of a new satellite signal.

Slip corrections $\Phi c^{s}(i-1)$ generated by the correction unit 616 (after a delay of one unit imposed by delay unit 618) are applied to the increments by operator 610 to generate corrected increments **ΔΦ c (i)** as follows:

$$\Delta\Phi c\ (i) = \Delta\Phi c(i) - \Phi c^{s}(i-1) \qquad (19)$$

Next, the channel indicator alarms 624 are analyzed by the channel indicator analyzer 622 and the channels marked with alarms are deleted from further processing by the integrated converter 612. If the number of the channels remaining for processing is at least four, then the corrected increments **ΔΦ c (i)** of the remaining channels are provided to the integrated converter 612 to generate $\Delta\hat{\Phi}$ (i) as follows:

$$\Delta\hat{\Phi}\ (i) = H(i) \cdot G(i) \cdot \Delta\Phi c^{c}(i) \qquad (20)$$

Here, matrices **H** and **G** (as described above) are calculated only for the remaining channels. Next, the vector of residuals **δ(i)** for the corrected increments is generated by operator 614 as follows:

$$\delta(i) = \Delta\Phi c^{c}(i) - \Delta\hat{\Phi}\ (i) \qquad (21)$$

The residuals are then provided to the correction unit 616 where cycle slip-corrections are generated as described above in accordance with equation (12). As described above, these corrections, after the imposition of a delay by delay unit 618, will be used for the calculation associated with the next measurement period. As seen, the correction loop in this embodiment of the anomaly indicator module is closed. In fact, the correction loop will work if alarms of the channel indicators appear.

The decision module 620 operates in manner similar to that described above in accordance with the decision module 322 of Fig. 3. For example, the results obtained in the

Claims:

1. A method for detecting anomalous phase measurements in a satellite differential navigation system in which a first satellite receiver and a second satellite receiver each compute phase measurements on a plurality of satellite channels, said method comprising the steps, performed for each of a plurality of iterations, of:

a) generating a combined phase difference vector;

b) generating a phase mismatch vector representing the difference between said combined phase difference vector and an estimated combined phase difference vector;

c) generating an averaged estimate vector representing the averaged estimate of said phase mismatch vector over said channels;

d) generating a residual vector representing the difference between said phase mismatch vector and said averaged estimate vector;

e) generating a vector of controlling signals by linear transformation of said residual vector and said averaged estimate vector;

f) generating said estimated combined phase difference vector by successively storing components of said vector of controlling signals for each of said channels; and

g) detecting anomalous phase measurements by analyzing said residual vector.

2. The method of claim 1 wherein said combined phase difference vector $\mathbf{\Phi c}$ comprises phase differences $(\Phi_{c_1}..\Phi_{c_j}..\Phi_{c_N})$ for a $j\text{-}th$ satellite channel, and wherein step a) of generating a combined phase difference vector further comprises the step of:

calculating said phase difference vector $\mathbf{\Phi c}$ as $\mathbf{\Phi c} = \mathbf{\Phi}^{\mathbf{B}} - \mathbf{\Phi}^{\mathbf{R}}$ where vector $\mathbf{\Phi}^{\mathbf{B}}$ comprises the full phases measured by one of said satellite receivers for each $j\text{-}th$ satellite channel $(\Phi_{B1}..\Phi_{Bj}..\Phi_{BN})$ and vector $\mathbf{\Phi}^{\mathbf{R}}$ comprises the full phases measured by the other satellite receiver for each $j\text{-}th$ satellite channel $(\Phi_{R1}..\Phi_{Rj}..\Phi_{RN})$.

3. The method of claim 1 wherein said first and second satellite receivers are dual frequency (f1 and f2) receivers and wherein said combined phase difference vector $\mathbf{\Phi c}$ comprises phase differences $(\Phi_{c_1}..\Phi_{c_j}..\Phi_{c_N})$ for a $j\text{-}th$ satellite channel, and wherein step a) of generating a combined phase difference vector further comprises the step of:

calculating said phase differences Φ_{c_j} of said phase difference vector $\mathbf{\Phi c}$ as

$\Phi c_j = (\Phi^B{}_{2j} - \Phi^R{}_{2j}) - (\Phi^B{}_{1j} - \Phi^R{}_{1j})(f2 / f1)$

where $\Phi^B{}_{2j}$ and $\Phi^B{}_{1j}$ represent the full phase measured by one of the satellite receivers at each *j-th* satellite channel at frequencies f2 and f1 respectively, and where $\Phi^R{}_{2j}$ and $\Phi^R{}_{1j}$ represent the full phase measured by the other of the satellite receivers at each *j-th* satellite channel at frequencies f2 and f1 respectively.

4. The method of claim 1 wherein said step c) of generating an averaged estimate vector $\Delta\Psi$ further comprises the step of:

calculating said average estimate vector $\Delta\Psi$ as

$$\Delta\Psi = \left(\sum_{j=1}^{N} w_j \cdot \Delta\Phi c_j \right) / \left(\sum_{j=1}^{N} w_j \right)$$

where $\Delta\Phi c_j$ represents the components of said phase mismatch vector for a *j-th* satellite channel, w_j represents a weight coefficient for each *j-th* satellite channel, and N represents the number of satellite channels.

5. The method of claim 1 wherein step c) of generating an averaged estimate vector $\Delta\Psi$ further comprises the step of:

calculating said average estimate vector $\Delta\Psi$ as $\mathbf{\Delta\Psi = H \cdot G \cdot \Delta\Phi c}$ where $\mathbf{H}$ is a matrix of directional cosines, $\mathbf{\Delta\Phi\, c}$ represents said phase mismatch vector, and $\mathbf{G}$ is a matrix defined by $\mathbf{G=(H^TR^{-1}H)^{-1}H^TR^{-1}}$ where $\mathbf{R}$ is a covariance matrix of phase mismatches.

6. The method of claim 1 wherein said step e) of generating a vector of controlling signals further comprises the step of:

generating said vector of controlling signals in combined loop filters of each of said plurality of channels.

7. The method of claim 6 where each of said combined loop filters generates a control signal (U_{cj}) for a *j-th* channel according to the following:

$$U_{1j}(i) = \sum_{k=0}^{i} \gamma\, \delta_j(k)$$

th satellite channel ($\Phi_{B1}..\Phi_{Bj}..\Phi_{BN}$) and vector Φ^R comprises the full phases measured by the other satellite receiver for each *j-th* satellite channel ($\Phi_{R1}..\Phi_{Rj}..\Phi_{RN}$).

23. The apparatus of claim 21 wherein said first and second satellite receivers are dual frequency (f1 and f2) receivers and wherein said combined phase difference vector $\mathbf{\Phi c}$ comprises phase differences ($\Phi c_1..\Phi c_j..\Phi c_N$) for a *j-th* satellite channel, and wherein said phase difference generator generates said phase differences Φc_j of said phase difference vector $\mathbf{\Phi c}$ as

$$\Phi c_j = (\Phi^B{}_{2j} - \Phi^R{}_{2j}) - (\Phi^B{}_{1j} - \Phi^R{}_{1j})(f2 / f1)$$

where $\Phi^B{}_{2j}$ and $\Phi^B{}_{1j}$ represent the full phase measured by one of the satellite receivers at each *j-th* satellite channel at frequencies f2 and f1 respectively, and where $\Phi^R{}_{2j}$ and $\Phi^R{}_{1j}$ represent the full phase measured by the other of the satellite receivers at each *j-th* satellite channel at frequencies f2 and f1 respectively.

24. The apparatus of claim 21 wherein said integrated discriminator generates said averaged estimate vector $\mathbf{\Delta\Psi}$ as

$$\Delta\Psi = \left(\sum_{j=1}^{N} w_j \cdot \Delta\Phi c_j \right) / \left(\sum_{j=1}^{N} w_j \right)$$

where $\Delta\Phi c_j$ represents the components of said phase mismatch vector for a *j-th* satellite channel, w_j represents a weight coefficient for each *j-th* satellite channel, and N represents the number of satellite channels.

25. The apparatus of claim 21 wherein said integrated discriminator generates said averaged estimate vector $\mathbf{\Delta\Psi}$ as $\mathbf{\Delta\Psi = H \cdot G \cdot \Delta\Phi c}$ where $\mathbf{H}$ is a matrix of directional cosines, $\mathbf{\Delta\Phi c}$ represents said phase mismatch vector, and $\mathbf{G}$ is a matrix defined by $\mathbf{G=(H^T R^{-1} H)^{-1} H^T R^{-1}}$ where $\mathbf{R}$ is a covariance matrix of phase mismatches.

26. The apparatus of claim 21 wherein said joint loop filter generates said vector of controlling signals in combined loop filters of each of said plurality of channels.

27. The apparatus of claim 26 wherein each of said at least one combined loop filters generates a control signal (U_{cj}) for a *j-th* channel according to the following: